(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 0 987 032 B1

(12) EUROPEAN PATENT SPECIFICATION

(45) Date of publication and mention of the grant of the patent:
01.12.2004 Bulletin 2004/49

(51) Int Cl.[7]: **A61L 27/00**, A61L 27/10, A61L 27/32, A61P 19/08

(21) Application number: **99202992.6**

(22) Date of filing: **14.09.1999**

(54) Ceramic material for osteoinduction comprising micropores in the surface of macropores

Keramikmaterial zur Osteoinduktion enthaltend Mikroporen an der Öberfläche von Makroporen

Matériau céramique pour l'ostéoinduction comprenant des micropores à la surface de macropores

(84) Designated Contracting States:
AT BE CH CY DE DK ES FI FR GB GR IE IT LI LU MC NL PT SE

(30) Priority: **15.09.1998 EP 98203084**

(43) Date of publication of application:
22.03.2000 Bulletin 2000/12

(73) Proprietor: **IsoTis N.V.**
3723 MB Bilthoven (NL)

(72) Inventors:
- **de Bruijn, Joost Dick**
  2517 AG Den Haag (NL)
- **de Groot, Klaas**
  2101 EL Heemstede (NL)
- **Huipin, Yuan**
  3706 AA Zeist (NL)
- **van Blitterswijk, Clemens Antoni**
  3467 PD Hekendorp (NL)

(74) Representative:
Prins, Adrianus Willem, Mr. Ir. et al
Vereenigde,
Nieuwe Parklaan 97
2587 BN Den Haag (NL)

(56) References cited:

EP-A- 0 267 624	**EP-A- 0 410 010**
FR-A- 2 697 243	**US-A- 4 195 366**
US-A- 4 629 464	**US-A- 5 017 518**
US-A- 5 355 898	**US-A- 5 531 794**
US-A- 5 549 123	**US-A- 5 766 618**

- **YOKOZEKI H ET AL: "Influence of surface microstructure on the reaction of the active ceramics in vivo" JOURNAL OF MATERIAL SCIENCE: MATERIALS IN MEDICINE, vol. 9, no. 7, July 1998 (1998-07), pages 381-384, XP002093992**
- **PEELEN J G J ET AL: "Sintered Hydroxylapatite as a bioceramic" PHILIPS TECHNICAL REVIEW, vol. 37, no. 9/10, 1977, pages 234-236, XP002093993 Philips BV, Eindhoven, NL**

Note: Within nine months from the publication of the mention of the grant of the European patent, any person may give notice to the European Patent Office of opposition to the European patent granted. Notice of opposition shall be filed in a written reasoned statement. It shall not be deemed to have been filed until the opposition fee has been paid. (Art. 99(1) European Patent Convention).

EP 0 987 032 B1

Description

[0001] The invention relates to an osteoinductive material and to a process for preparing said material.

[0002] Calcium phosphates such as hydroxyapatite are known to be osteoconductive, or bioactive. This means that they act as a template along which bone growth can occur. Further, bone formation can directly take place at the surface of the material, and a strong bond is obtained with bone tissue. Osteoinductivity, on the other hand, is regarded as a property of materials that induce the formation of bone tissue. In the past, this property has only been described in connection with materials that contain osteoinductive, proteinaceous factors such as bone morphogenetic proteins (BMP's).

[0003] Recently, however, several studies have been reported that indicate a possible osteoinductive capacity of calcium phosphates when implanted intramuscularly in dogs or baboons. Generally, it is assumed that the presence of a porous structure and a specific geometry of the implant plays a crucial role in the osteoinductive character of the implant.

[0004] Yamasaki et al., in Biomaterials 1992, vol. 13, no. 5, 308-312, have described to have found heterotopic bone formation around porous hydroxyapatite ceramic granules, but not around dense granules. The porous granules had a size between 200 and 600 μm, and a continuous and interconnected microporosity ranging in diameter from 2 to 10 μm.

[0005] European patent application 0 267 624 discloses a porous calcium phosphate based bone prosthesis having open pores with an average size of 0.01-2,000 μm and closed pores with an average size of 0.01-30 μm. The prosthesis is said to have both good workability and an adequate degree of biocompatability.

[0006] United States patent 5,017,518 discloses a process for producing calcium phosphate ceramics having a porous surface. The process comprises preparing untreated calcium phosphate ceramics, which comprises a mixture of hydroxyapatite and tricalcium phosphate, and treating said untreated ceramics with an acidic solution to selectively dissolve the tricalcium phosphate in the surface of the ceramics.

[0007] In the Journal of Material Science: Materials in Medicine, vol. 9, no. 7, July 1998, pages 381-384, Yokozeki et al. have described a bone graft of beta-tricalcium phosphate. The graft is prepared by sintering at 900°C and has micropores of 0.2-0.5 μm and macropores of 0.15-0.4 mm, and a porosity of 60%.

[0008] European patent application 0 410 010 discloses a hydoxyapatite bone implant with micropores having a size below 5 μm, macropores having a size above 100 μm, and a porosity of up to 80%.

[0009] United States patent 4,195,366 discloses a polycrystalline whitlockite ceramic in either pore-free or porous form. The ceramic has a crystallite size of 0.3-3 μm.

[0010] United States patent 4,629,464 discloses a bone filling material composed of a sintered hydroxyapatite with micropores of 0.02-0.1 mm, macropores of 0.2-2.0 mm, and a porosity of 40%. The material is prepared by sintering a slurry of hydroxyapatite in the presence of hydrogen peroxide at a temperature of 1100-1300°C.

[0011] The present invention aims to provide a material having an improved osteoinductivity. It is an object of the invention to provide a material that is suitable to be used as an implant in living organisms and to function as a (temporary) substitute for bone tissue. Thus, the material should be both biocompatible and biodegradable.

[0012] Surprisingly, it has been found that this object is achieved by the provision of a ceramic material having both macropores and micropores of specific sizes. Hence, the invention relates to an osteoinductive biomaterial, which is based on a ceramic material and which has a total porosity of 20 to 90%, wherein macropores are present having a size ranging from 0.1 to 1.5 mm, and wherein micropores are present in the surface of the macropores, said micropores having a size ranging from 0.05 to 20 μm.

[0013] The material of the invention shows excellent osteoinductive behaviour in living tissue. The formation of bone tissue at the surface of the material of the invention assists in a favourable acceptation of an implant made of said material. Moreover, the formation of the bone tissue accelerates the recovery of any damage in the bone structure, which forms the reason for applying the implant.

[0014] An osteoinductive biomaterial according to the invention is based on a ceramic material. The biomaterial may for instance be a medical implant formed of a ceramic material. It is also possible that the biomaterial is a medical implant of a different material, such as a metal or a polymeric material, on which the ceramic material is present in the form of a coating. Another possibility is described by M.L. Gaillard and C.A. van Blitterswijk in J. Mater. Sci., Materials in Medicine, 5:695-701 (1994). This possibility concerns a copolymer having hydrogel-like properties, which may be calcified in the presence of calcium and phosphate ions.

[0015] In principle, any ceramic material that is both sufficiently biocompatible and sufficiently biodegradable to be used as an implant in living tissue can be used. Preferably, the ceramic material is capable of providing a calcium phosphate surface, either *in vitro* or *in vivo*, which has the present specific surface structure. It is further preferred that the ceramic material is capable of adsorbing biologically active agents, such as growth factors (BMP's etc.), either *in vitro* or *in vivo*. Suitable examples of ceramic materials include calcium phosphates, glass ceramics and materials containing calcium phosphates and/or glass ceramics.

[0016] Preferably, the ceramic material is a calcium phosphate. Preferred calcium phosphates are octacalcium phosphate, apatites, such as hydroxyapatite and

carbonate apatite, whitlockites, such as α-tricalcium phosphate and β-tricalcium phosphate, and combinations thereof.

[0017] An important aspect of the invention is the physical structure of the osteoinductive biomaterial. The material comprises both macropores and micropores. The total porosity ranges from 20 to 90%, preferably from 40 to 70%.

[0018] The macropores of the material have a size of from 0.1 to 1.5 mm. Preferably, the size of the macropores lies between 0.2 and 1 mm. It has been found that the indicated sizes of the macropores have a significant beneficial influence on the osteoinductive character of the material. Further preferred is that the macropores are interconnected.

[0019] The micropores of the material have a size of from 0.05 to 20 μm. In accordance with this embodiment, the formation of bone tissue is highly promoted. A preferred range for the size of the micropores is from 0.5 and 10 μm. The micropores are at least present in the surface of the macropores. The microporosity of the material's surface preferably lies between 40 and 60%.

[0020] In accordance with the invention, the biomaterial preferably consists of crystals. Preferably, the size of the crystals is similar to the size of the micropores. When this is the case, the biomaterial has a preferable microrugosity. Thus, the size of the crystals lies preferably between 0.05 and 20 μm, more preferably between 0.5 and 10 μm.

[0021] The osteoinductive biomaterial according to the invention may advantageously be used in applications where bone formation is desired. Thus, the material may be used for the manufacture of medical implants, particular implants for bone substitution. The material may further be used for the manufacture of a scaffold for tissue engineering a bone equivalent.

[0022] The invention further relates to processes for preparing an osteoinductive biomaterial as described above.

[0023] In a first embodiment, the osteoinductive biomaterial may be prepared by sintering a ceramic material under such conditions, that an osteoinductive biomatieral as described above is obtained. The ceramic material is, before the sintering, in a calcined state. The sintering is preferably performed at a temperature between 1000 and 1275°C, treated with an aqueous solution of an organic acid and washed to remove the acid.

[0024] Preferably, the sintering is carried out at a temperature between 1150 and 1250°C. The duration of the sintering step may suitably be chosen between 6 and 10 hours, preferably between 7 and 9 hours. It has further been found advantageous to perform the sintering while the ceramic material is submersed in a powder of the ceramic material. This beneficially affects the reactivity of the surface of the material, and consequently also the bioactivity (dissolution, re-precipitation).

[0025] After the sintering, the material is preferably ground with sandpaper, such as Si-C sandpaper, to remove chemical surface impurities.

[0026] Subsequently, the material is treated with an aqueous solution of an acid. Suitable acids in this regard are any etching acids, i.e. any acids which lead to a slight dissolution of the calcium phosphate based material. The use of the following acids has been found to lead to extremely favourable results: maleic acid, hydrochloric acid, phosphoric acid, and combinations thereof. The concentration of the acid in the solution is preferably chosen such that the pH of the solution lies between 0 and 4, more preferably between 1 and 3.

[0027] After the acid treatment, which preferably lasts between 3 and 15 minutes, the ceramic material is washed to remove the acid. The washing may suitably be performed using ethanol, water or a combination thereof.

[0028] Finally, it is preferred to subject the obtained osteoinductive biomaterial to a sterilisation treatment, such as a steam sterilisation.

[0029] In a second embodiment, a slurry of a powder of the ceramic material in an aqueous solution of a negative replica forming agent, which during sintering burns or evaporates, is sintered under such conditions that an osteoinductive biomaterial as described above is obtained. Suitable negative replica forming agents include hydrogen peroxide, baking powder or bicarbonate. Preferably, hydrogen peroxide is used.

[0030] Thus, first, the powder is added to an aqueous solution of the negative replica forming agent to form a slurry. The concentration of the negative replica forming agent in the slurry preferably lies between 0.5 and 15 wt.%, more preferably between 1 and 5 wt.%, based on the weight of the solution. The powder is added in a ratio of between 0.5 to 5, preferably 1 to 3 grams per 1 millilitre of the solution. The slurry may then be cast in a mould having a desired shape and size and sintered. The sintering is preferably carried out at a temperature between 800 and 1300°C, more preferably between 1000 and 1200°C for a period of up to 12 hours. Care should be taken that the sintering period is not so long that a dense material is obtained.

[0031] The invention will now be elucidated by the following, non-restrictive examples.

EXAMPLE 1

Preparation of materials

[0032] Four different types of porous hydroxyapatite (HA) discs (approximately 6x6x2 mm in size) were prepared:

A: HA sintered at 1300°C (Figure 1)
B: HA sintered at 1250°C (Figure 2)
C: HA sintered at 1300°C, and treated with acid (Figures 3 and 5)
D: HA sintered at 1250°C, and treated with acid (Figures 4 and 6).

Figures 1-4 are 2500x enlarged; figures 5 and 6 are 81.5x enlarged.

[0033] Two types of porous calcium phosphate blocks (18x18x25 mm) were prepared by sintering hydroxyapatite at either 1250°C (HA1250; white colour) or 1300°C (HA1300; blue colour). The HA1300 was prepared by a subsequent sintering of HA1250 blocks, for 8 hours at 1300°C (the temperature was raised from room temperature by 100°C per hour, kept constant for 8 hours, and lowered by 100°C per hour to room temperature), while submersed in HA powder to obtain a surface reactive layer. HA1300 contained approximately 10-12% by weight of β-tricalcium phosphate. The sides of all blocks were ground with #220 Si-C sandpaper to remove chemical surface impurities, and the blocks were cut in 4 parts of approximately 8x8x25 mm. A total of twenty, 2 mm thick sections were prepared from each material type. The corners of each material (HA1250 and HA1300) were placed in 2.5% maleic acid for 10 minutes. Subsequently, all sections (40 in total) were ultrasonically cleaned/washed for 5 minutes in alcohol (70%) and distilled water respectively, individually packaged and sterilised by steam sterilisation.

Experimental design and surgical procedure

[0034] Four pockets were created in the paravertrebal muscle in the back of 7 goats (2 pockets left and 2 pockets right from the spinal cord) for each of the four implants. the implants were inserted in a randomised manner in each pocket, ensuring that each implant type is only present once in each goat. Each material type was evaluated in sevenfold for statistical analysis, which necessitates the use of 7 goats.

[0035] Seven adult Dutch milk goats (approximately 40-60 kg; CAE/CL arthritis free and examined by a veterinary surgeon) were obtained from a professional stock breeder, and kept in quarantine for 4 weeks prior to the experiment. Prior to surgery, the goats were weighed and amphicilin 20% (2ml/50 kg body weight) was administered by intramuscular injection. The surgical procedure was performed under general inhalation anaesthesia. After an intravenous injection of Thiopental, a mixture of nitrous oxide, oxygen and fluothane maintained anaesthesia. Left and right, 10 cm from the spinal cord, the back of each goat was shaved at two places, respectively. For each of the four intramuscular implantation sites (in each goat), an incision of approximately 3 cm was made, followed by blunt dissection until the muscle fascia of the paravertrebal muscle was reached. using a Mayo scissors, an incision of 15 mm was made in the muscle fascia and an intramuscular pocket was subsequently prepared by blunt dissection followed by implant insertion. The muscle fascia and skin were closed in separate layers using vicryl 3-0 sutures. Six months post-operatively, the animals were sacrificed using an intravenously administered overdose of thiopental and potassium chloride.

Implant processing and histology

[0036] After sacrificing the animals, the implants were excises. Six implants of each material type were placed in Karnovsky's fixative for at least one week (4°C), while the seventh implant was stored at -70°C for biochemical analysis. The fixed implants were subsequently dehydrated through a series of ethanol and embedded in Methyl Methacrylate. Semi-thin sections were cut on a modified innerlock diamond saw, perpendicular to the longitudinal plane of the implants, and examined by light microscopy for *de novo* bone formation.

Results

[0037] After the six months implantation time, histology revealed that a thin fibrous tissue capsule surrounded the HA samples. The adjoining muscle tissue had a normal appearance. None of the HA1250 and HA1300 sample revealed signs of degradation. With the acid treated HA1250 samples, some loosened HA particles could be observed at the periphery of the implant, while abundant surface degradation was observed with the acid treated HA1300. Especially at the outer surface of these implants, many loosened HA particles were present in the surrounding tissues. Noteworthy is the finding that particularly at both the outer surface and the pore surfaces of acid treated HA1250 implants, numerous individual mononucleated and multinucleated giant cells were present that were more or less cubicoidal in morphology. Furthermore, in the acid treated HA1250 samples, *de novo* bone formation was apparent. This bone tissue was normal in appearance and contained osteoblasts and osteocytes. None of the other materials revealed any bone formation.

EXAMPLE 2

Preparation of material

[0038] A 2.0 M solution (A) of calcium nitrate tetrahydrate (AR) in distilled water (AD) was prepared. A 2.0 M second solution (B) was prepared of diammonium hydrogen phosphate (AR) was prepared in distilled water (AD). Under stirring and adjusting the pH just over 8.0 using ammonia (AR), the second solution (B) was slowly added to the first solution (A) in a ratio of 1.63:1 (vol/vol).

[0039] The obtained mixed solution was kept overnight in a cupboard at ambient temperature. The next day, the pH of the solution was adjusted to over 10.00 using ammonia. The solution was left to age at ambient temperature.

[0040] After 30 days, the clear solution was tipped to leave a slurry which was washed five times. with distilled water (AD). Next, the slurry was filtered over 3 filter papers (2* #3 and 1* #1) under negative pressure. The cake in the filter was washed three times with distilled water (AD) while taken care that in between each wash-

ing cycle the filter cake was dry but not broken. The cake was then dried in an oven at 50°C and ground to a powder. The resulting powder was sieved over a 140 mesh sifter to obtain a biphasic calcium phosphate (BCP) powder.

[0041] The BCP powder was mixed with a 3.0% aqueous hydrogen peroxide solution at a ratio of 1 gram powder in 1 ml solution. The resulting slurry was poured into a mould consisting of a plastic container (diameter 38 mm, height 60 mm). The mould was placed in an oven at 60°C for foaming and drying. Next, the dry porous blocks were carefully removed from the container and sintered at 1100°C for 10 hours (the temperature was raised from room temperature to 1100°C in 10 hours, and after sintering, the temperature was decreased to room temperature in the same time frame.)

Animal experiments

[0042] To test the osteoinductivity of the above prepared biphasic calcium phosphate (BCP), BCP cylinders were implanted in the thigh muscles of dogs for 90 days. Bone formation induced by BCP was analysed with histology, back scattered electron microscopy (BSE) and energy disperse X-ray (EDX) microanalysis.

1. Preparation of the implants:

[0043] BCP blocks machined from BCP ceramic body as obtained above were polished into cylinders (5mm diameter, 6mm length). The implants were ultrasonically washed with 70% ethanol for 15 minutes, with demineralised water twice (15 minutes each), dried at 50°C, and then steam sterilised (121°C) for 30 minutes before implantation.

2. Animal preparation:

[0044] Eight healthy dogs (male and female, 2-6 years old, 10-15 kg) were selected and used to test the osteoinductivity of BCP.

3. Surgical procedure:

[0045] The surgical procedure was performed under general anaesthesia (30mg pentobarbital sodium/kg body weight) and under sterile conditions. After shaving, the skin was sterilised with iodine and 70% ethanol. With a scalpel, a longitudinal incision was made in the skin. By a blunt separation, the thigh muscle was disposed. Again, with a scalpel, a small longitudinal incision was made in the thigh muscle and a muscle pouch was obtained by blunt separation. One BCP cylinder was inserted into the muscle pouch (one BCP implant was implanted in each dog). The surgical procedure was finished by suturing the muscle pouch and skin in layers with silk thread. The animals were intramuscularly injected with 1.6 million units penicillin 3 times in 3 days.

4. Sample harvest:

[0046] Ninety days after surgery, the dogs were sacrificed by an overdose of pentobarbital sodium, and the implanted samples with surrounding tissues were harvested and immediately fixed in 4% buffered (pH=7.4) formaldehyde. A total of 8 samples were collected from 8 dogs.

5. Histological preparation:

[0047] The fixed samples were washed with PBS (3 changes of PBS, 2 days each), then dehydrated with series ethanol solution (70%, 80%, 90%, 96% and 100%X2) and embedded in MMA. Thin undecalcified sections (10-20 micrometer) were made and stained with Methylene Blue and Basic Fuchsin for histological observation. Some sections were coated with carbon and observed with BSE and EDX.

6. Results:

Incidence of bone formation

[0048]

- Bone formation was found in all samples (8 in 8) Identification of induced bone
- Histologically, bone was found in the pores inside the implants. Mineralised bone matrix, osteoblast seams and osteocytes were obvious. BSE observation showed that the bone tissue was mineralised and contained osteocyte lacunas, EDX analysis showed that the mineralised tissues were composed of Ca and P.

7. Conclusion

[0049] Soft tissue implantation (both intramuscularly and subcutaneously) is the study model of osteoinduction. The bone formation in BCP ceramic followed intramuscular implantation showed that the tested BCP is osteoinductive.

EXAMPLE 3

Preparation of material

[0050] A mixture was prepared of SiO_2 (relative amount 29.4% in weight, AR, particle size 0.5-10 microns), $NaHCO_3$ (relative amount 34.1% in weight, AR), $CaCO_3$ (relative amount 28.6% in weight, AR) and Na_2HPO_4 (relative amount 7.9% in weight, AR). This mixture was sintered for 10 hours at 1000°C and for 2 hours at 1300°C. After cooling, a glass ceramic material was obtained.

[0051] The glass ceramic was broken mechanically into small particles, which were subsequently ball-milled

to a fine powder. The powder was sieved through a 200 mesh filter. The glass ceramic powder was mixed with a 3.0% aqueous hydrogen peroxide solution at a ratio of 2.4 gram powder in 1 ml solution. The resulting slurry was poured into a plastic container (diameter 38 mm, height 60 mm). The mould was placed in an oven at 50°C for foaming and drying. Next, the dry porous blocks were sintered at 800-1000°C for 2 hours (the increase in temperature was 5°C/min.). Eventually, the blocks were allowed to cool naturally in the oven.

Animal experiments

[0052] To test the osteoinductivity of the above prepared glass ceramics, glass ceramic cylinders were implanted in the thigh muscles of dogs for 90 days. Bone formation induced by glass ceramics was analysed with histology, back scattered electron microscopy (BSE) and energy disperse X-ray (EDX) microanalysis.

1. Preparation of the implants:

[0053] Glass ceramic blocks machined from glass ceramic body as prepared above were polished into cylinders (5mm diameter, 6mm length). The implants were ultrasonically washed with 70% ethanol for 15 minutes, with demineralised water twice (15 minutes each), dried at 50°C, and then steam sterilised (121°C) for 30 minutes before implantation.

2. Animal preparation:

[0054] Eight health dogs (male and female, 2-6 years old, 10-15 kg) were selected and used to test the osteoinductivity of glass ceramic.

3. Surgical procedure:

[0055] Surgery was performed under general anaesthesia (30mg pentobarbital sodium/kg body weight) and under sterile conditions. After shaving, the skin was sterilised with iodine ethanol and 70% ethanol. With a scalpel, a longitudinal incision was made in the skin. By a blunt separation, the thigh muscle was disposed. Again, with a scalpel, a small longitudinal incision was made in the thigh muscle, a muscle pouch was obtained by blunt separation. One glass ceramic cylinder was inserted into the muscle pouch (one implant was implanted in each dog). The surgical procedure was finished by suturing the muscle pouch and skin with silk thread in layers. The animals were intramuscularly injected with 1.6 million units penicillin for 3 days.

4. Sample harvest:

[0056] Ninety days after surgery, the dogs were sacrificed by a pentobarbital sodium overdose, and the implanted samples were harvested with surrounding tissues and immediately fixed in 4% buffered (pH=7.4) formaldehyde. A total of 8 samples were collected from 8 dogs.

5. Histological preparation:

[0057] The fixed samples were washed with PBS (3 changes of PBS, 2 days each), then dehydrated with series ethanol solution (70%, 80%, 90%, 96% and 100%X2) and embedded in MMA. Thin undecalcified sections (10-20 micrometer) was made and stained with Methylene Blue and Basic Fuchsin for histological observation. Some sections were coated with carbon and observed with BSE and EDX.

6. Results:

Incidence of bone formation

[0058]

- Bone formation was found in 6 samples of 8 Identification of induced bone
- Histologically, bone was found in the pores inside the implants. Mineralised bone matrix, osteoblast seam and osteocytes were obvious. BSE observation showed that the bone tissues were mineralised with osteocyte lacunas, EDX analysis showed that the mineralised tissues were composed of Ca and P.

7. Conclusion:

[0059] Soft tissue implantation (both intramuscularly and subcutaneously) is the study model of osteoinduction. The bone formation in glass ceramic followed intramuscular implantation showed that the tested glass ceramic is osteoinductive.

Claims

1. An osteoinductive biomaterial, which is based on a ceramic material and which has a total porosity of 20 to 90%, wherein macropores are present having a size ranging from 0.1 to 1.5 mm, and wherein micropores are present in the surface of the macropores, said micropores having a size ranging from 0.05 to 20 μm.

2. An osteoinductive biomaterial according to claim 1, wherein the macroporosity is between 0.2 and 1 mm.

3. An osteoinductive biomaterial according to claim 1 or 2, wherein the microporosity lies between 0.5 and 10 μm.

4. An osteoinductive biomaterial according to any of the preceding claims, wherein the total porosity lies between 40 and 70%.

5. An osteoinductive biomaterial according to any of the preceding claims, which is composed of crystals having a crystal size between 0.05 and 20 μm, preferably between 0.5 and 10 μm.

6. An osteoinductive biomaterial according to any of the preceding claims, wherein the ceramic material is a calcium phosphate, glass ceramic or a material containing a calcium phosphate and/or glass ceramic.

7. An osteoinductive biomaterial according to claim 6, wherein the ceramic material is a calcium phosphate chosen from the group consisting of octacalcium phosphate, apatites, such as hydroxyapatite and carbonate apatite, whitlockites, such as β-tricalcium phosphate and α-tricalcium phosphate, and combinations thereof.

8. An osteoinductive material according to any of the preceding claims, wherein the microporosity of the material's surface is between 40 and 60%

9. A process for preparing an osteoinductive biomaterial according to any of the preceding claims, wherein a ceramic material is sintered at a temperature between 1000 and 1275°C, treated with an aqueous solution of an acid, and washed to remove the acid.

10. A process according to claim 9, wherein the acid is chosen from the group consisting of maleic acid, hydrochloric acid, phosphoric acid and combinations thereof.

11. A process according to claims 9 or 10, wherein the pH of the aqueous solution lies between 0 and 4.

12. A process according to claims 9-11, wherein the washing is carried out using ethanol, water or a combination thereof.

13. A process for preparing an osteoinductive biomaterial according to any of the claims 1-8, wherein a slurry is prepared of a powder of a ceramic material in an aqueous solution of a negative replica forming agent, which slurry is sintered at a temperature of 800-1200°C.

14. A process according to claim 13, wherein the negative replica forming agent is hydrogen peroxide.

15. A process according to claims 9-14, wherein the osteoinductive biomaterial is sterilised.

16. An osteoinductive biomaterial according to any one of claims 1-8, obtainable by a process according to any one of claims 9-15.

17. A medical implant comprising an osteoinductive biomaterial according to any one of claims 1-8 or 16.

18. A scaffold for tissue engineering a bone equivalent comprising an osteoinductive biomaterial according to any one of claims 1-8 or 16.

19. The use of a biomaterial according to any one of claims 1-8 or 16 in the manufacture of a medicament for inducing formation of bone tissue in a living organism, preferably a mammal.

Patentansprüche

1. Osteoinduktives Biomaterial, das auf einem keramischen Material basiert und das eine Gesamtporosität von 20 bis 90 % aufweist, worin Makroporen mit einer Größe im Bereich von 0,1 bis 1,5 mm vorhanden sind und worin Mikroporen in der Oberfläche der Makroporen anwesend sind, wobei besagte Mikroporen eine Größe im Bereich von 0,05 bis 20 μm haben.

2. Osteoinduktives Biomaterial nach Anspruch 1, worin die Makroporosität zwischen 0,2 und 1 mm ist.

3. Osteoinduktives Biomaterial nach Anspruch 1 oder 2, worin die Mikroporosität zwischen 0,5 und 10 μm liegt.

4. Osteoinduktives Biomaterial nach einem der vorhergehenden Ansprüche, worin die Gesamtporosität zwischen 40 und 70 % liegt.

5. Osteoinduktives Biomaterial nach einem der vorhergehenden Ansprüche, das aus Kristallen mit einer Kristallgröße zwischen 0,05 und 20 μm, vorzugsweise zwischen 0,5 und 10 μm zusammengesetzt ist.

6. Osteoinduktives Biomaterial nach einem der vorhergehenden Ansprüche, worin das keramische Material Calciumphosphat, Glaskeramik oder ein Material, enthaltend Calciumphosphat und/oder Glaskeramik, ist.

7. Osteoinduktives Biomaterial nach Anspruch 6, worin das keramische Material Calciumphosphat, ausgewählt aus der Gruppe, bestehend aus Octacalciumphosphat, Apatiten wie Hydroxyapatit und Apatitcarbonat, Whitlockiten wie β-Tricalciumphosphat und α-Tricalciumphosphat, und Kombinationen derselben, ist.

8. Osteoinduktives Material nach einem der vorhergehenden Ansprüche, worin die Mikroporosität der Oberfläche des Materials zwischen 40 und 60 % ist.

9. Verfahren für die Herstellung eines osteoinduktiven Biomaterials nach einem der vorhergehenden Ansprüche, worin ein keramisches Material bei einer Temperatur zwischen 1000 und 1275°C gesintert, mit der wässrigen Lösung einer Säure behandelt und gewaschen wird, um die Säure zu entfemen.

10. Verfahren gemäß Anspruch 9, worin die Säure ausgewählt wird aus der Gruppe, bestehend aus Maleinsäure, Salzsäure, Phosphorsäure und Kombinationen derselben.

11. Verfahren nach Anspruch 9 oder 10, worin der pH-Wert der wässrigen Lösung zwischen 0 und 4 liegt.

12. Verfahren gemäß Anspruch 9 bis 11, worin das Waschen ausgeführt wird unter Verwendung von Ethanol, Wasser oder Kombinationen derselben.

13. Verfahren zur Herstellung eines osteoinduktiven Biomaterials nach einem der Ansprüche 1 bis 8, worin eine Aufschlämmung hergestellt wird aus einem Pulver eines keramischen Materials in einer wässrigen Lösung eines eine Negativkopie bildenden Mittels, wobei die Aufschlämmung bei einer Temperatur von 800 bis 1200°C gesintert wird.

14. Verfahren nach Anspruch 13, worin das die Negativkopie bildende Mittel Wasserstoffperoxid ist.

15. Verfahren nach Anspruch 9 bis 14, worin das osteoinduktive Biomaterial sterilisiert wird.

16. Osteoinduktives Biomaterial nach einem der Ansprüche 1 bis 8, erhältlich durch ein Verfahren nach einem der Ansprüche 9 bis 15.

17. Medizinisches Implantat, umfassend ein osteoinduktives Biomaterial nach einem der Ansprüche 1 bis 8 oder 16.

18. Gerüst für die künstliche Gewebeherstellung eines Knochenersatzstückes, umfassend ein osteoinduktives Biomaterial nach einem der Ansprüche 1 bis 8 oder 16.

19. Verwendung eines Biomaterials nach einem der Ansprüche 1 bis 8 oder 16 in der Herstellung eines Medikaments für die induktive Bildung von Knochengewebe in einem lebendigen Organismus, vorzugsweise einem Säugetier.

Revendications

1. Biomatériau ostéoinducteur, qui est à base d'un matériau céramique et qui a une porosité totale de 20% à 90%, dans lequel sont présents des macropores ayant une taille comprise dans la gamme de 0,1 à 1,5 mm, et dans lequel des micropores sont présents dans la surface des macropores, lesdits micropores ayant une taille comprise dans la gamme de 0,05 à 20 μm.

2. Biomatériau ostéoinducteur selon la revendication 1, dans lequel la macroporosité est comprise entre 0,2 et 1 mm.

3. Biomatériau ostéoinducteur selon la revendication 1 ou 2, dans lequel la microporosité est comprise entre 0,5 et 10 μm.

4. Biomatériau ostéoinducteur selon l'une quelconque des revendications précédentes, dans lequel la porosité totale est de 40 à 70%.

5. Biomatériau ostéoinducteur selon l'une quelconque des revendications précédentes, qui est composé de cristaux ayant une dimension cristalline comprise entre 0,05 et 20 μm, de préférence entre 0,5 et 10 μm.

6. Biomatériau ostéoinducteur selon l'une quelconque des revendications précédentes, dans lequel le matériau céramique est un phosphate de calcium, une vitrocéramique ou un matériau contenant un phosphate de calcium et/ou une vitrocéramique.

7. Biomatériau ostéoinducteur selon la revendication 6, dans lequel le matériau céramique est un phosphate de calcium choisi dans le groupe consistant en phosphate octacalcique, apatites telles que hydroxyapatite et carbonate apatite, whitlockites, telles que phosphate β-tricalcique et phosphate α-tricalcique, et leurs combinaisons.

8. Matériau ostéoinducteur selon l'une quelconque des revendications précédentes, dans lequel la microporosité de la surface du matériau est comprise entre 40 et 60%.

9. Procédé pour la préparation d'un biomatériau ostéoinducteur selon l'une quelconque des revendications précédentes, dans lequel un matériau céramique est fritté à une température comprise entre 1000 et 1275°C, traité avec une solution aqueuse d'un acide, et lavé pour éliminer l'acide.

10. Procédé selon la revendication 9, dans lequel l'acide est choisi dans le groupe consistant en acide maléique, acide chlorhydrique, acide phosphorique

et leurs combinaisons.

11. Procédé selon les revendications 9 ou 10, dans lequel le pH de la solution aqueuse est compris entre 0 et 4.

12. Procédé selon les revendications 9 à 11, dans lequel le lavage est effectué avec de l'éthanol, de l'eau ou une combinaison de ceux-ci.

13. Procédé pour la préparation d'un biomatériau ostéoinducteur selon l'une quelconque des revendications 1 à 8, dans lequel il est préparé une suspension d'une poudre d'un matériau céramique dans une solution aqueuse d'un agent formant une réplique négative, laquelle suspension est frittée à une température de 800 à 1200°C.

14. Procédé selon la revendication 13, dans lequel l'agent formant une réplique négative est du peroxyde d'hydrogène.

15. Procédé selon les revendications 9 à 14, dans lequel le biomatériau ostéoinducteur est stérilisé.

16. Biomatériau ostéoinducteur selon l'une quelconque des revendications 1 à 8, pouvant être obtenu par un procédé selon l'une quelconque des revendications 9 à 15.

17. Implant médical comprenant un biomatériau ostéoinducteur selon l'une quelconque des revendications 1 à 8 ou 16.

18. Ossature pour construction de tissu formant un équivalent d'os comprenant un biomatériau ostéoinducteur selon l'une quelconque des revendications 1 à 8 ou 16.

19. Utilisation d'un biomatériau selon l'une quelconque des revendications 1 à 8 ou 16 dans la fabrication d'un médicament pour induire la formation de tissu osseux dans un organisme vivant, de préférence un mammifère.

Figure 1

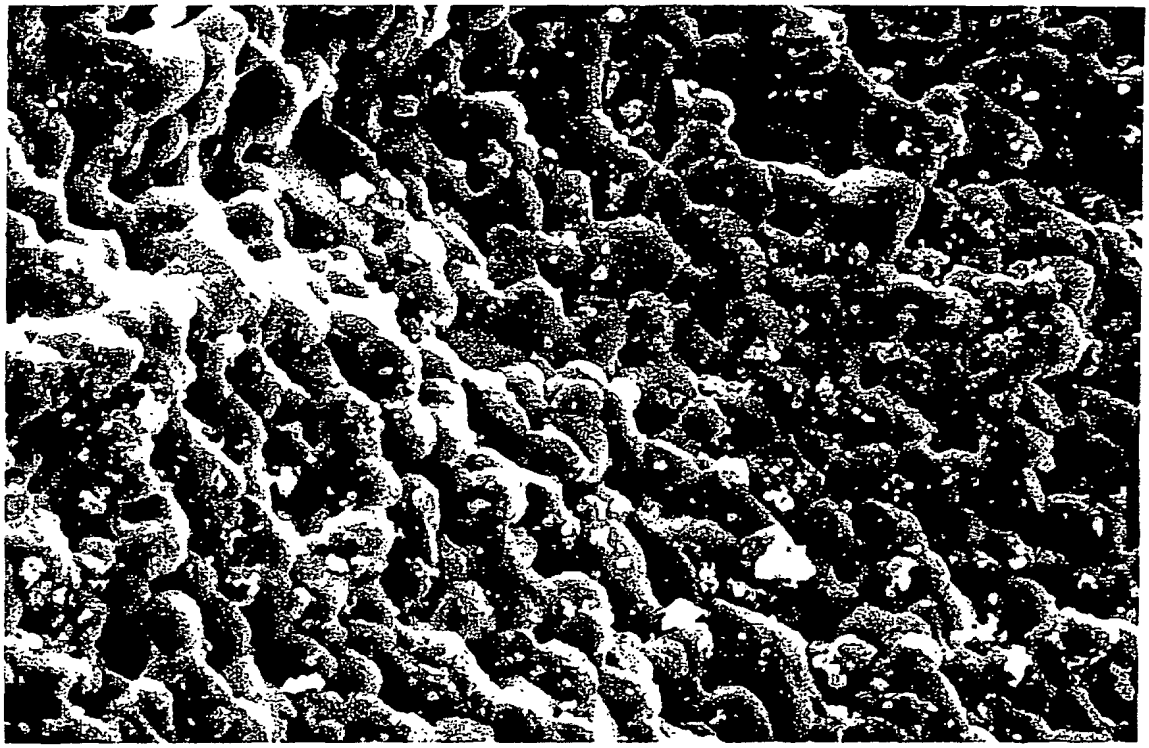

Figure 2

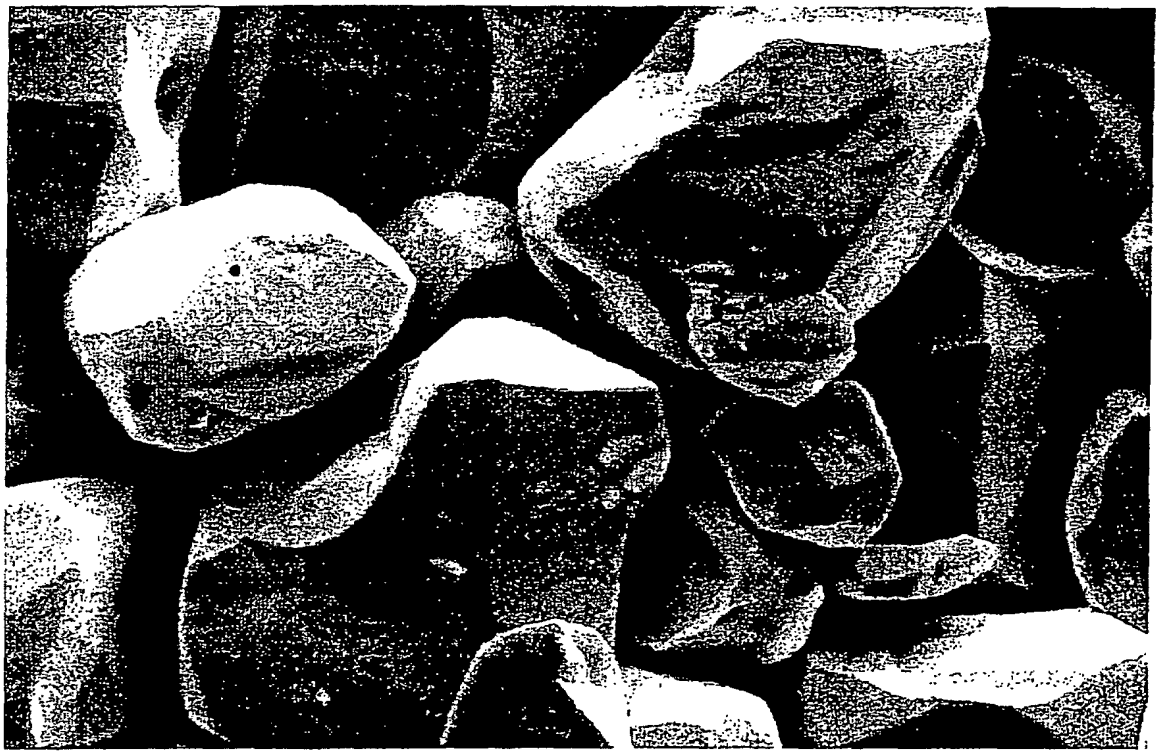

Figure 3

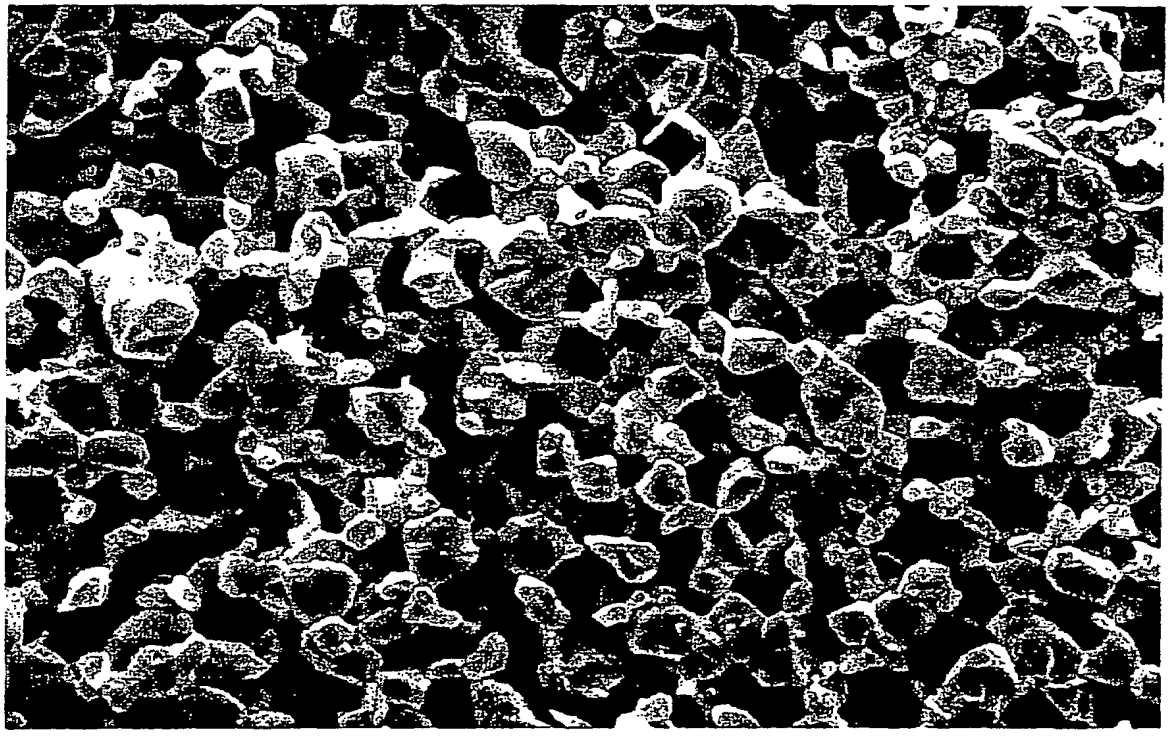

Figure 4

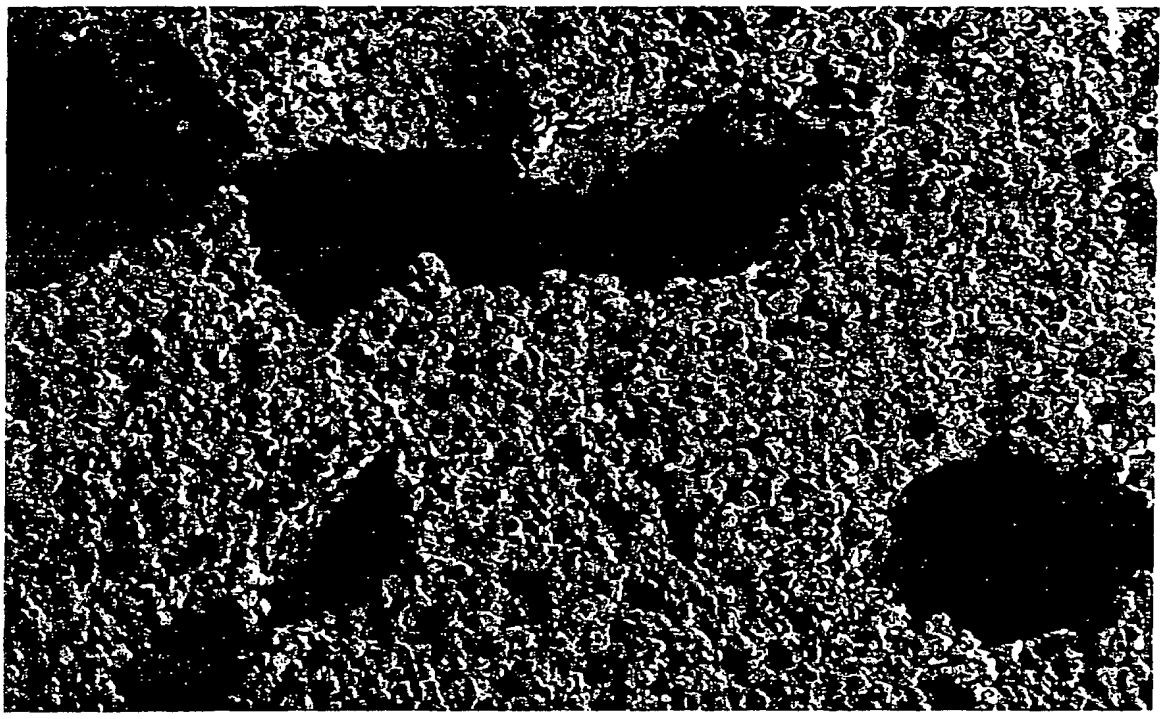

Figure 5

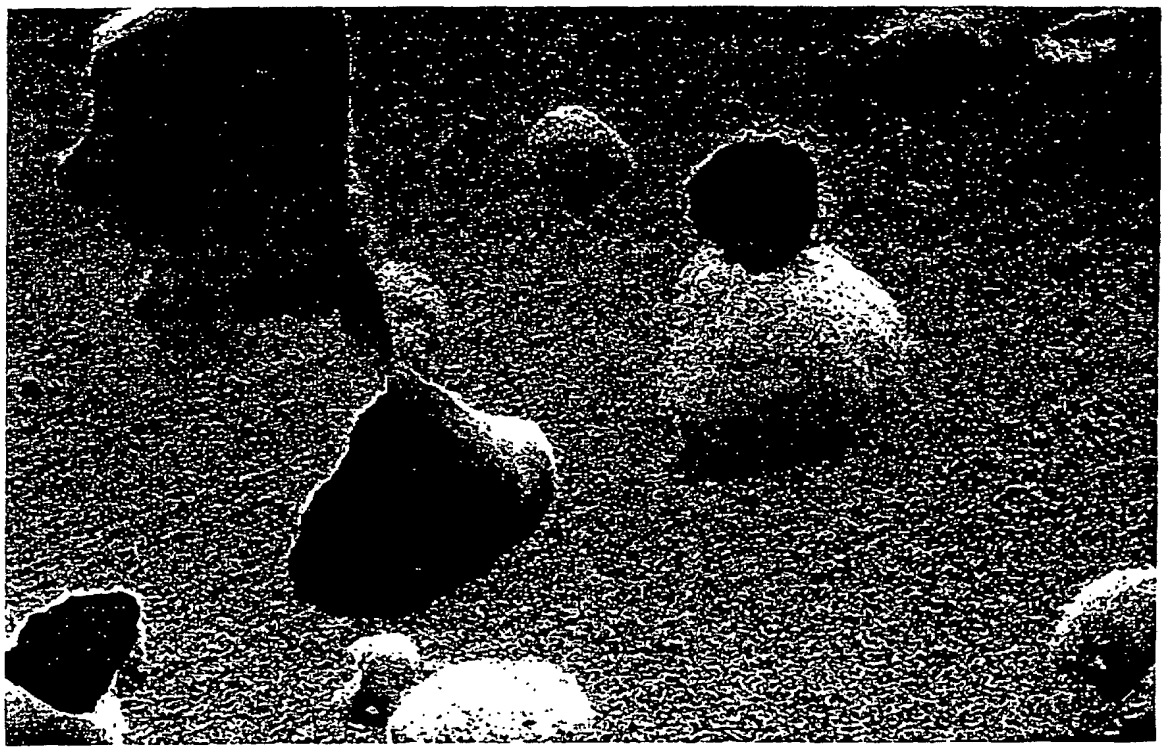

Figure 6